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SEPTIC TANK DISPOSAL SYSTEMS AS PHOSPHORUS SOURCES FOR SURFACE WATERS

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A 4-year groundwater monitoring study was conducted in the immediate vicinity of an active septic tank wastewater disposal system in the sandy substrate in Burnett County of northwestern Wisconsin to determine the potential for this method of wastewater disposal to contribute to excessive fertilization of surface waters. To monitor the movement of the effluent and the character of the area groundwater, selected parameters were measured in water samples collected from an array of wells located up and down groundwater gradient from the septic tank tile field.

During the course of this study, movement of septic tank effluent in the groundwater was indicated by measured values of several of these parameters. However, there was no evidence of the transport of the phosphate from septic tank effluent through the groundwater even at the monitoring point closest to the tile field (about 15 m down groundwater gradient from the tile field). The results of this study confirm the conclusions drawn from similar studies in other areas reported in the literature, that phosphorus from septic tank wastewater disposal system effluent is usually not readily transported through the groundwater. Therefore, septic tank wastewater disposal systems generally do not contribute significant amounts of phosphorus to surface waters to contribute to their excessive fertilization.

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SEPTIC TANK DISPOSAL SYSTEMS AS PHOSPHORUS SOURCES FOR SURFACE WATERS

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to that knowledge which is essential in order for EPA to establish and enforce pollution control standards which are reasonable, cost effective, and provide adequate environmental protection for the American public.

William C. Galegar
Director

ABSTRACT

A four-year groundwater monitoring study was conducted in the immediate vicinity of an active septic tank wastewater disposal system in the sandy substrate in Burnett County of northwestern Wisconsin to determine the potential for this method of wastewater disposal to contribute to excessive fertilization of surface waters. To monitor the movement of the effluent and the character of the area groundwater, the following parameters were measured in water samples collected from an array of wells located up and down groundwater gradient from the septic tank tile field: specific conductance, pH, alkalinity, Na^{+}, Cl^{-}, K^{+}, Mg^{++}, Ca^{++}, soluble orthophosphate, total phosphorus, and various forms of nitrogen.

During the course of this study, movement of septic tank effluent in the groundwater was indicated by measured values of several of these parameters. However, there was no evidence of the transport of the phosphate from septic tank effluent through the groundwater even at the monitoring point closest to the tile field (about 15 m down groundwater gradient from the tile field). The results of this study confirm the conclusions drawn from similar studies in other areas reported in the literature, that phosphorus from septic tank wastewater disposal system effluent is usually not readily transported through the groundwater. Therefore, septic tank wastewater disposal systems generally do not contribute significant amounts of phosphorus to surface waters to contribute to their excessive fertilization.

This report was submitted in partial fulfillment of Grant R-804549 by the University of Texas at Dallas under the sponsorship of the US Environmental Protection Agency.

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CONVERSION TABLE

MULTIPLY	BY	TO OBTAIN
meters	3.28	feet
cm	0.39	inches
liters	0.26	gallons
$l/cm^2/day$	245.8	gpd/ft^2
l/day	0.26	gpd
percent/m	0.305	percent/ft
kg	2.2	lbs

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SECTION 1

INTRODUCTION

The Voyager Village recreational development located in Burnett County, Wisconsin, has been criticized because of potential problems of ground and surface water contamination resulting from septic tank wastewater disposal system effluent. The primary concern was the potential for aquatic plant nutrient (nitrogen and phosphorus compounds) contamination of surface waters which could result in excessive growth of algae and other aquatic plants in nearby lakes.

Normally, effluents from septic tank wastewater disposal systems contain large quantities of nitrogen in the form of ammonia and organic nitrogen and phosphorus in the forms of ortho and condensed phosphate and organic phosphorus. A large part of the organic nitrogen and phosphorus compounds are present in particulate forms. In the soil, the particulate forms are filtered out in a relatively short distance from a tile field. Bacterial reactions convert part of the particulate organic forms to soluble ammonia and orthophosphate. The condensed phosphates are primarily derived from detergents and are in the form of tripolyphosphate and pyrophosphate. In aerobic systems, the tripolyphosphate is hydrolyzed to pyrophosphate and orthophosphate; the pyrophosphate is hydrolyzed to orthophosphate. Although no data are available on the hydrolysis of the condensed phosphates in aerobic systems such as those found near the tile field of a septic tank system, it is reasonable to suspect that hydrolysis will occur in groundwater systems although the rate could be somewhat slower than in surface waters.

The ammonia and phosphate present in septic tank effluent tends to be sorbed by the aquifer material in most groundwater

systems. However, in the presence of oxygen in the groundwater the ammonia will be oxidized to nitrate. The nitrate is poorly sorbed by aquifer materials and is readily transported in groundwater. There are some groundwater systems with low dissolved oxygen content that tend to cause some loss of nitrate through denitrification reactions to nitrogen gas. Although this reaction is generally thought to be a biochemical process, there is evidence that chemical denitrification occurs. It should be emphasized that the extent of the denitrification reaction is such that the majority of the nitrate is transported by groundwater and is not lost as nitrogen gas.

Generally, phosphate is fixed by the soil particles in the aquifers and normally is poorly transported in groundwater. However, in some sand aquifers, like those found in many parts of Wisconsin, the sorption capacity of the aquifer material for phosphate is lower than for many clay soils. It is not possible, however, to generally state that all sand aquifer systems will transport phosphorus. The key to holding phosphorus within an aquifer system is the presence of small amounts of clay minerals, iron oxide, aluminum oxide or limestone, all of which would tend to fix the phosphate in the soil. Therefore, a sand aquifer system which contains some of these materials would retain phosphate more readily than a sand aquifer system without them.

In order to investigate the potential for phosphate and other contaminant transport from septic tank wastewater disposal systems that are being used in the Voyager Village development area (Burnett County, Wisconsin) it was decided to conduct a several-year field study which would provide data necessary to determine the likelihood of significant phosphate transport from the septic tank wastewater disposal systems effluent to surface waters in the development area.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from the groundwater monitoring study in the Voyager Village development area that there was transport of septic tank effluent down groundwater gradient from the septic tank tile field. This was generally evidenced by patterns of specific conductance, chloride, and alkalinity values. There was also limited transport of nitrate in the groundwaters. During the four-year study period, there was no evidence of phosphorus from septic tank effluent in the observation wells down groundwater gradient from the septic tank wastewater disposal system.

If area lakes receiving groundwater from the development area are typically phosphorus limited, the installation of septic tank wastewater disposal systems in the Voyager Village development area should not degrade existing surface water quality. However, where lakes of the area are nitrogen limited during the period of maximum algal growth, there is a potential for some increased aquatic plant growth due to contributions of nitrate from septic tank effluent.

The results of this study strongly support the conclusions drawn from similar studies reported in the literature, that the phosphate present in septic tank wastewater disposal system effluent would not, in general, be expected to contribute significantly to the excessive fertilization of surface waters.

While significant transport of phosphorus from septic tank wastewater disposal system effluent to surface waters is expected to be rare, there are situations where this would occur. In those situations where it is not possible to construct a sewerage collection system, consideration should be given to

modifying the septic tank disposal system to increase phosphate retention capacity. There are a number of engineering questions that remain to be resolved in order to provide some general guidelines for design of the modified system in order to minimize cost and maximize phosphate removal. It is recommended that studies be conducted to provide general guidelines on the design of modified septic tank wastewater disposal systems to increase their phosphate retention capacity.

There is little need for additional research on the mechanisms of phosphorus immobilization in soils. While there are still several unanswered questions in this area, further work along this line is likely to yield a rather limited amount of additional information which could be used to readily ascertain whether a particular septic tank wastewater disposal system is contributing a significant amount of phosphate to nearby surface waters. Questions of this type have to be approached on a case-by-case basis so that through the monitoring of an appropriate series of wells and an understanding of ground and surface water hydrology, it would be possible to establish whether or not phosphate transport was occurring from a particular system. It should be possible to develop a laboratory phosphate transport test system in which the expected amount of transport that may occur in the field could be estimated. It is recommended that studies in this area be conducted.

SECTION 3

LITERATURE REVIEW*

FACTORS CONTROLLING PHOSPHORUS TRANSPORT

There are a number of factors controlling phosphorus transport from septic tank wastewater disposal system effluent to surface waters in sufficient quantities and in available forms to affect surface water quality. Based on previous studies of the chemistry of phosphorus in natural water systems, it is expected that the potential of a soil to remove phosphate from septic tank wastewater disposal system effluent is controlled by the mineralogy of the area soils rather than by the soil particle size. A review of the literature pertaining to reduction of phosphate concentrations by soil and subsoil systems indicates that one of the primary factors in P removal is the tendency of phosphorus to sorb on aquifer materials or on soil or subsurface particles. In addition, in calcareous areas, phosphate can be precipitated as hydroxyapatite in the groundwater system. Lee (1976b) pointed out that in hardwater areas such as are found in the southern half of Michigan, the likelihood of significant phosphate transport from septic tank wastewater disposal system effluent to the surface waters is greatly reduced because of the calcium carbonate present in the soil and subsoil systems.

The importance of sorption and precipitation reactions is readily demonstrated when one examines the chemical characteristics of groundwaters. It is rare that groundwaters have high phosphorus content. The total phosphorus is rarely more than a few tenths of a milligram per liter (Dudley and Stephenson, 1973; New York State Department of Health, 1972; Stumm and Morgan, 1970). In the review of phosphate removal by sands and soils by Tofflemire et al. (1973), it is stated that the natural groundwater concentrations

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*Standard units of measure have been converted to the metric system. Refer to Conversion Table, p. viii, for explanation.

often range from 0.01 to 0.06 mg/l P. Also, according to Enfield (1976), the phosphorus concentration in naturally occurring groundwater is typically 0.05 mg/l or less. As discussed by Enfield and Bledsoe (1975), seven literature values for phosphorus concentrations in ground and subsurface drainage water from agricultural land and beneath wastewater treatment systems showed that concentrations generally ranged from about 0.005 to 0.1 mg P/l. The low concentrations of phosphorus present in groundwaters can be attributed to a combination of sorption and precipitation reactions. These same reactions would be applicable to the phosphorus present in septic tank wastewater effluents.

FIELD STUDIES ON PHOSPHATE TRANSPORT FROM SEPTIC TANK SYSTEMS

Thomas (1976) indicated that Allum used the work of Dillon and Rigler (1975) and Viraghavan and Warnock (1976a) as support for his position that there is limited retention of phosphorus by soils adjacent to septic tank wastewater disposal systems. Soils used in the Viraghavan and Warnock study, Thomas claimed, were similar to those in Michigan. Examination of the paper of Viraghavan and Warnock (1976a) shows that no mineralogical information is given upon which one can judge the similarity or lack thereof of the soils in Michigan compared to soils near Ottawa, Canada, where their study was conducted. The authors (Viraghavan and Warnock) had significant experimental problems in their study. Even if the results are taken at face value, their data indicates 25 to 50 percent retention of phosphorus. This amount is considerably greater than the 10 percent figure that Thomas attempted to justify.

The other paper cited by Thomas in support of his position was that of Dillon and Rigler (1975). Upon examination of the retention coefficients formulated by Brandes et al. (1974) presented therein, in only the five coarse sands tested was the fraction of phosphorus retained less than 50 percent. The other sands and sand-silt or sandy-clay mixtures showed 63 to 88 percent phosphorus retention. One of these coarse sands had a phosphorus

retention of 48 percent. Only two coarse sands showed retention of less than 10 percent.

Keeley (1976), Chief, US EPA Groundwater Research Program, stated that, in general, the only place they have encountered significant phosphate transport in groundwaters is in association with coarse sands, and even there, the movement in many instances is very slow.

Henderson (1969) stated that in his investigation of Gull Lake, Michigan, there appeared to be a relationship between the presence of septic systems 15 m or less from the lake and the observation of aquatic weed growth along the immediate shore. He also stated, however, that aquatic weed growth was more frequently noticed by those residents who water and fertilize their lawns. Visual examination of his figures showing these relationships shows a strong relationship between residents who fertilize their lawns and observation of aquatic weed growth in the adjacent shoreline. Henderson's justification for the possibility that this relationship may be tenuous is inconclusive since relationships between types of fertilization practices and increased aquatic plant growth observations were not properly weighted according to numbers of people using each fertilization method. Based on data given, it would be difficult to sort effects of fertilization and distance of septic tanks from the lake.

In five samples collected in tile lines draining toward Gull Lake, Ellis and Erickson (1969b) found that phosphorus content varied from 0.028 to 0.07 mg/l P, indicating negligible transport of phosphorus from those septic tank system effluents.

In the Gull Lake investigations of the effect of phosphorus load on distance of phosphorus movement, Ellis (1971) found that at four of the ten sites sampled, the profiles contained so much phosphorus, apparently from fertilizers according to Ellis, that the determination of phosphorus movement from septic tank discharge was very difficult. Three additional locations showed sufficient interference from fertilizers to make the determination of the distance of phosphorus movement from the septic tank discharge difficult. He concluded that, in general, based on the

remaining sites, the distance phosphorus moved increased with increased soil P rating (a measure of phosphorus load from the residences).

Ellis (1971) also studied the distance of phosphorus movement for the various soil types in the area. All of the soil types surrounding Gull Lake (Bellefontain sandy loam, Bellefontain loam, Fox sandy loam, Fox gravelly loam, Fox loam, muck with fill) were represented in the study except the Ostemo sand. The quantity of this sand in the Gull Lake area was reported to be small. In this part of his study, movement of phosphorus from the surface (from fertilizers) made it difficult to assess movement from septic tank effluent. Only four of the 16 locations showed no apparent movement from the surface. In the 12 locations where estimations of movement could be made, only three showed phosphorus movement from the point of effluent discharge greater than 6 m. Maximum phosphorus movement found was 9 m. Ellis stated that until the soils become saturated with phosphorus, nearly 98 percent of the phosphorus entering the ground would be adsorbed by soils. He made the observation that 75 percent of the lawns surrounding Gull Lake were saturated with phosphorus from fertilizers. This would allow the phosphorus in those areas to largely pass through the soil.

An estimation of the annual phosphorus load transported into Houghton Lake, Michigan, by groundwaters, was made by Childs (1974). This estimation was based on groundwater sample analyses, an area water budget, and net flow calculations. It was estimated that groundwater transports from all sources a maximum of 450 kg of phosphorus into Houghton Lake annually. This represents 98 percent removal of the estimated 18,000 kg of phosphorus discharged annually by local residents via septic systems. Since the phosphorus mass is not present in local groundwaters and only trace amounts could be adsorbed above the groundwater, Childs concluded that phosphorus is sorbed below the water table. He further concluded that it appeared that the adsorptive capacity of soil may be as great under water saturated conditions as under aerated conditions. Childs concluded that the majority of phosphorus

discharged through septic tank systems in the Houghton Lake area has been, and is being, retained by soils and sediments within the zone of saturation.

In a study of six septic tank disposal systems in Nassau and Suffolk Counties (Long Island), New York, conducted by the New York State Department of Health (1972), it was concluded that phosphate reductions were rapid and almost total in the distances from septic tank wastewater disposal systems studied. Soil porosities at Sites 1, 2, and 3 ranged from 29 to 38 percent. The soil characteristic at Site 1 was predominantly medium to coarse sand and gravel; distance to the groundwater was 2.4 m. There were two cesspools on the site, one receiving the majority of the waste, the second receiving some waste and overflow from the first cesspool. Despite the fact that the first pool was full and overflowing into the second pool, substantial leaching from the first pool was indicated. Only data from the monitoring of one pool (apparently the first) was presented. Decreases in phosphorus content of 97 to 99 percent by 24 m downgradient from the one cesspool site monitored were found, where total P ranged from 1.7 to 0.99 mg/l. Between 26 and 57 percent decrease was found at 4.6 m below the cesspool. Average percent reduction found at that site was about 4.6 percent/m. An adjustment of this decrease for dilution showed that removal of 1.7 to 2.1 percent/m was due to factors other than dilution in the saturated zone.

At their Site 2 (cesspool site), also in medium to coarse sands and gravel where the distance to the groundwater was 2.4 m, 99 to greater than 99.9 percent total phosphate reduction was found at a point 20 m downgradient where concentrations in the groundwater varied from 0.03 to 0.6 mg/l P. Between 32 and 69 percent reduction of phosphates was found 7.6 m downgradient from the cesspool.

The third site in the Long Island study, on which one cesspool was located, contained medium to coarse sands and gravel. Distance to the groundwater was 9 m; average groundwater

velocity was 0.37 m/day. In the first 1.5 m downgradient, in unsaturated soils, 44 and 76 percent phosphorus reductions were found on the two sampling dates. At 14 m, the phosphorus had been reduced a total of 72 and 97.7 percent, respectively. Average reductions of phosphorus were 2.5 percent/m and 9.0 percent/m through the unsaturated soil zone (from the cesspool to the well located about 4.6 m from the cesspool). Average phosphate reduction in the saturated zone by about 18 m from the cesspool was, discounting decrease by dilution, 4.7 to 8 percent/m, indicating factors other than dilution accounting for the majority of decrease in concentration in the saturated zone. In the limited study of vertical migration done on this site, 34 and 52 percent phosphorus reduction took place in the first 0.46 m of unsaturated material beneath the cesspool.

Subsoil at Site 4 consisted of silty sand with traces of gravel; distance to the groundwater was 5 m. There were two cesspools at the site, but only one received wastes during the study period. Net P reductions of 98.6 to 99.8 percent were found within 9.4 m downgradient from the cesspools resulting in background phosphorus levels in the groundwaters within 9.4 m of the cesspools. Overall average reductions during travel through the unsaturated zone were 25.1 and 27.0 percent/m, whereas in the saturated zone, decreases were 15.6 and 32 percent/m, respectively. Disregarding dilution effects in the saturated zone, 11.9 and 26.3 percent/m decreases, respectively, were found.

The Long Island, New York study also monitored two septic tank-tile field systems, one in medium to fine sand (Site 5) and another in sandy clay, grit and stones (Site 6). Distances to groundwater were 1.4 and 2.4 m at Sites 5 and 6, respectively. Their summary of percent P reduction showed 63 to 82 percent reduction within the Site 5 tile field. Beneath the tile field at Site 6, P reduction ranged from 99.7 to 99.8 percent with resulting groundwater concentrations of 0.14 to 0.21 mg/l P. They concluded that the increase in P reduction at Site 6 could be attributed to optimum conditions for phosphate reduction, namely

finer soil to encourage entrapment of precipitated phosphates as well as the relatively new unsaturated soil horizon which would enhance adsorption potential. In addition, greater water use at Site 5 and character of sewage produced there purportedly influenced reduction. In these investigations. only total P values were presented. The authors indicated that the ortho and total phosphate values were essentially the same.

Hansen (1968) and Boyle and Polkowski (1970) (as cited in Dudley and Stephenson, 1973) monitored septic tank wastewater disposal system effluent migration in soil and groundwater adjacent to the system in an area of silt and loam overlying glacial outwash sand and gravel in Wisconsin. They concluded that soil at the site removed essentially all of the phosphorus present in the septic tank effluent.

Dudley and Stephenson (1973) monitored migration of phosphorus from septic tank effluents at 11 sites in central and northern Wisconsin. Efficient P reduction was accomplished at the septic tank system at Site 1 (built in 1968 on the shore of an oligotrophic lake in outwash sand where the depth to the water table was 3.4 m) as evidenced by generally low total P concentrations at wells downgradient from the tile field. When absorption field effluent was sampled concomitant with observation wells about 4.6 m downgradient, 99.1 to 99.9 percent P removal was found resulting in well concentrations of 0.3 and 0.04 mg/l P, respectively.

Dudley and Stephenson (1973) also found very effective P reduction at their second site, a dry well system in outwash sand built in 1965. Depth to the water table was 4 m. No concentrations greater than 0.65 mg/l P were found associated with this area. Effective P reduction at Site 3, in medium sandy soil, was evidenced by the fact that concentrations of total P rarely exceeded 0.3 mg/l in wells monitored adjacent to the absorption field. Concentrations within 12 m of the absorption field were generally in the several hundredths of a mg/l range. That system was built in 1971; depth to the water table was about 3 m. The same degree of decrease was found at Site 4, built in 1969 in outwash sands, where depth to the water table was about 2.5 m.

Dudley and Stephenson (1973) found that their Site 5 septic tank (constructed in 1970) in an area of sandy loam overlying medium sand where depth to the groundwater ranged from 0.6-6.4 m contained high phosphorus concentrations up groundwater gradient from the septic tank system due to natural enrichments through nutrient flushing of organic lake bottom sediments located upgradient. The single down groundwater gradient observation well, 9 m from the tile field, however, contained only 0.03 to 0.11 mg/l P during the study period, demonstrating effective P reductions from percolating effluent.

Data from Sites 6 and 7 (in clayey sand soil), according to Dudley and Stephenson, were difficult to interpret due to sampling difficulties and differences in sampling techniques. Those septic tank systems were built in 1968 and 1964, respectively. Low levels of P in the pumped wells at Site 7 where depth to the groundwater was 1-2 m did indicate a decrease in phosphorus from the effluent, however. Groundwater directly below the absorption field at Site 8 (apparently medium sand) showed some transport of phosphorus and migration of P in the groundwater. This phosphorus would likely not affect water quality in the nearby lake since the movement of groundwater was away from the lake at that point.

As monitored at Site 8 well points located approximately 0.9 m on either side of the absorption field, there was generally some lateral movement of P in the groundwater. Concentrations ranging from about the same to 35 times greater than background levels were found in these wells. The most elevated P concentrations were found at the well site about 3 m from the end of the tile field. This well was located on the downgradient edge of the septic tank. It is possible that the very high groundwater P concentrations at that well site were the result of leakage of the septic tank itself, rather than from tile field drainage.

Data from Site 9, in outwash sands where depth to the water table was 3-7 m, showed P contamination in the well about 0.9 m downgradient from the dry well (built in 1967). As was pointed out by Dudley and Stephenson (1973) this may be due in major part

to system design. Such a system is installed in coarse sand so that lateral flow in the unsaturated zone in response to soil moisture tension would be minimal. This coarse sand and gravel substrate apparently had little or no ability to adsorb P during the downward percolation of the effluent.

Site 10, also a dry well system, built in 1969 in a sandy soil where the depth to the water table was 0.6-4 m , demonstrated effective reduction of P from the effluent. This was evidenced by low levels of phosphorus in the well located several feet downgradient from the dry well and in those outside the gravel fill area.

The final site in the Dudley and Stephenson study was an absorption field built in 1974 on about 17 m of unsaturated outwash sand. Due to differences in sampling technique, the use of the phosphate data generated was limited. Of six sets of samples collected at the two downgradient wells, four sets showed higher total P concentrations at the well immediately downgradient from the field than at the well about 9 m farther downgradient This indicates that there was some P reduction occurring.

Periodic occurrence of elevated phosphorus levels in upgradient wells at a few of the sites pointed to some local reversals of gradient near the center of the groundwater mound at the discharge. Two of those sites, however, were recharged by lake water which may have contributed to the higher upgradient concentrations.

It was demonstrated in this study that although phosphorus enrichment of groundwater occurred in a few coarse sand systems, effective decreases in phosphorus took place in medium and fine sand soils. In most sites monitored, low total P concentrations were found in well stations 4.6 m downgradient from input, and beyond.

Viraghavan and Warnock (1976b) studied migration of phosphorus from an experimental tile field in sandy loam, silt loam to silty clay, loam soil in Ottawa, Canada. One sample set showed apparently effective P removal by a point 9.1 m from the

experimental tile field. It appeared from diagrams presented that concentrations in wells beyond that point could have been influenced by flow from laterals of the main septic system adjacent to the experimental field. Although Viraghavan and Warnock concluded that the decrease of phosphate achieved in this study was not high, it was difficult to determine patterns of removal from the data presented.

Reneau and Pettry (1976) conducted a study during 1972-1974 in Chesterfield County, Virginia on Goldsboro sandy loam and Varina sandy loam to determine effects of septic tank effluent on soil P fractions and their distribution. Both soil areas were moderately well drained and had seasonally perched water tables. The system on Varina soil had been in use for approximately 15 years, receiving an estimated 2700 l/day effluent. The system in the Goldsboro soil was four years old and received an estimated 770 l/day effluent.

Data from 46 groundwater samples adjacent to the drainfields in Varina soil indicated that dissolved P consisted primarily of soluble ortho P with only minor contributions from polyphosphates and organic P. In the Varina soil, increased concentrations were found at the 89-99 cm depth. Soluble orthophosphate concentrations at that depth showed a decrease from an average effluent concentration of 5.5 mg/l to an average of 1.05 mg/l at 0.15 m from the drainfield, an 80 percent P reduction. This decrease generally continued with distance from the drainfield. At 6.1 m from the drainfield, greater than 90 percent reduction in average soluble ortho P was found. By 12 m from the discharge, the concentration was an average of 0.01 mg/l P, a 99 percent removal of phosphate. Using the maximum concentrations found at the 89-99 cm depth 12 m from the drainfield, removal was 80 percent. Concentrations in the lower, plinthic horizon (all averaged at or below 0.01 mg/l P) according to Reneau and Pettry, showed that that horizon was an effective barrier to vertical soluble ortho P movement. No detectable soluble ortho P was found in perched water tables not receiving septic tank effluent.

An examination of P fractions in the Varina soil horizons at different depths downgradient from the drainfield area showed increased concentrations, as compared to the control profile, of all fractions in the top 18 cm at 0.15 m from the drainfield. Reneau and Pettry attributed this to previous fertilization practices. Phosphorus concentrations at 0.15 m from the drainfield reached a maximum in the B21t and B22t horizons (41-76 cm depth) and decreased rapidly in the plinthic horizon (beyond 76 cm depth). The accumulation of P from septic tank effluent, they concluded, was concentrated in the argillic horizons. The increase in "fixed" P in that horizon at 0.15 m reflects not only water movement in a horizontal direction above the plinthic horizon, but also the influence of soil physical and chemical properties of these horizons on P fixation. At 3 m from the drainfield in the B21t and B22t horizons, there was essentially no difference in P fractions from those found in the central profile.

At the Goldsboro location, soluble ortho P was present primarily at the 142-152 cm sampling depth. From an average drainline concentration of 11.8 mg/l P, average concentrations were decreased 92 percent by 0.15 m from the tile field. Concentrations generally decreased at that depth with increasing distance from the field. At 3 meters from the tile field, there had been a reduction of 98 percent, to an average of 0.21 mg P/l. On the average, there was no detectable phosphate at this depth, 13.5 m from the drainfield. Maximum concentrations there were 0.01 mg P/l. In the Goldsboro soil, the septic tank effluent generally had little influence on soil P fractions at 0.15 m. This was attributed to the youth and limited use of the system.

Reneau and Pettry stated that during periods of lower water tables at the Goldsboro site, soluble ortho P apparently moved primarily in a vertical direction in the saturated zone below the drainlines until the perched water table or restricting layer was intersected. Horizontal movement then occurred at the 142-152 cm depth. There was no indication that the phosphate moved into the 432 cm depth which was in the permanent groundwater table.

Smith and Myott (1975) reported that 57 percent of the 1.5 million people in Nassau County, N.Y. were served by sewers. The remaining population discharged 230 x 106 l/day sewage into the ground. They undertook a study to determine constituents of sewage origin in groundwater during 1971 and 1972. It indicated that the elevated levels of phosphorus (0-10 mg P/l) attributed to cesspool leachate were found in shallow observation wells but not in the selected Magothy aquifer wells beneath the more shallow aquifer.

Beek et al. (1977a) conducted a two-year study on a sewage farm drainfield on sandy soil near Tilburg, the Netherlands. This farm had been in use for 50 years during which time the drainfield was intermittently flooded (generally once a month). Averaged over the two-year monitoring period, they found removal of total and orthophosphates up to 96 percent between sewage water and field drainage water. They found that the accumulation of soil phosphates was limited to the top 50 cm soil layers; nonflood soils showed low levels of soil phosphate in the top 75 cm of soil compared with flooded soil. Adsorption reactions were proposed at the mechanisms involved, because of the high efficiency of phosphate removal despite limited contact with the soil.

Comparison of the chemical forms in which phosphates accumulated in sandy soil plots flooded intermittently for 30 years and for 50 years was made by Beek et al. (1977b). They showed that the distribution patterns of the different phosphate fractions were virtually the same in both plots. Because of this, in addition to the fact that the Al-combined phosphates prevailed, it was concluded that phosphate retention in these soils was still mainly governed by reactions with aluminum. The presence of active Al compounds, either available in the soil system prior to flooding or added as components of sewage water, according to Beek et al., will determine the ultimate storage capacity of the soil for phosphate binding in that soil.

Lee (1976a) studied the groundwater transport of nutrients (N and P) to Lake Sallie located in glacial outwash terrain of west central Minnesota. Evaluation of the contributions of

nitrogen and phosphorus was based on groundwater samples collected using seepage meters placed on the lake bottom (7 to 17 m from shore) adjacent to a residential and/or cropland area. Lee concluded that the contribution of phosphorus from groundwater including septic tanks near the lake was insignificant compared to the surface water phosphorus load.

It is concluded from these field studies on transport of phosphorus from septic tank wastewater system effluents that the likelihood of significant transport is small. Several other investigators who have reviewed this topic have reached similar conclusions. According to Okun (1972), in unsewered areas, which include about 30 percent of the total US population, although waters from the wastewater disposal systems may reach lakes and streams, the phosphates are held in the ground. He concluded that private sewage disposal systems are of little consequence to the eutrophication problems of the US.

Corey et al. (1967) estimated principal sources of phosphorus for Lake Mendota, Wisconsin. The contributions from private sewage systems (septic systems) were estimated by assuming that 5 percent of the phosphorus in the sewage eventually reaches surface waters. Corey et al. estimated that septic tank wastewater disposal systems contributed a minor fraction (2 percent) of the total phosphorus input.

It has been estimated that private sewage systems contributed 2.2 percent of the phosphorus load to surface waters of Wisconsin (Wirth and Hill, 1967). This contribution figure was based on the assumptions that all nutrients contributed by private sewage systems reached surface waters and that the systems were used year-round. They stated that not all systems were located in close proximity to surface waters and that it was likely that two-thirds or more of the septic systems on water front properties are not used for more than three or four months per year. Therefore, it is unlikely that septic tank wastewater disposal systems would represent significant sources of phosphorus that could contribute to the excessive fertilization of surface waters.

SUMMARY AND CONCLUSIONS FROM LITERATURE

It has been demonstrated by previous studies that the potential of a soil to remove phosphate from septic tank wastewater disposal system effluent is controlled by the mineralogy of the area soils, rather than by the soil particle size. In field studies, it was found that most soils, even medium sandy soils, exhibit substantial ability to reduce phosphate concentrations. Reductions found were typically in excess of 95 percent within relatively short distances from effluent sources. It has also been shown that the capacity of a soil to reduce effluent phosphorus concentrations is not necessarily finite.

It can be concluded, based on these studies, that it is unlikely that, under most circumstances, sufficient available phosphate would be transported from septic tank wastewater disposal systems to significantly contribute to the excessive aquatic plant growth problems in water courses recharged by these waters.

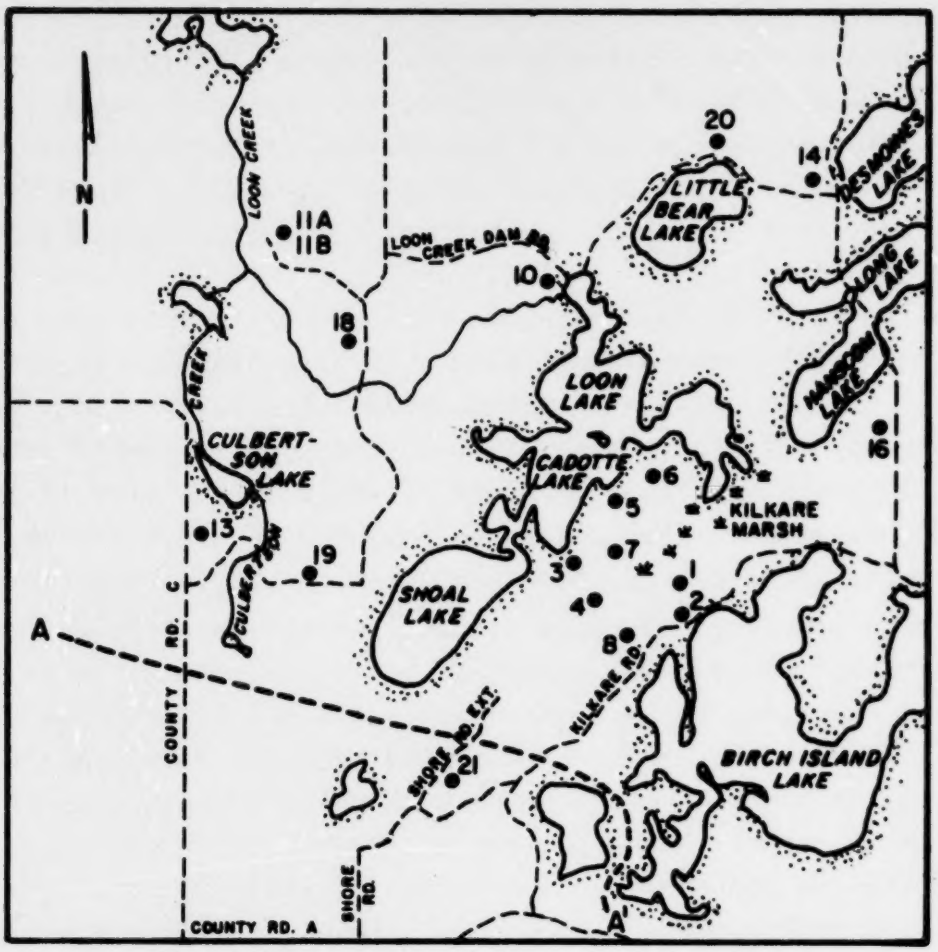
SECTION 4

EXPERIMENTAL PROCEDURES AND CHARACTERISTICS OF AREA

To determine soil characteristics, groundwater flow patterns, and general groundwater quality in the study area, 18 test wells were installed (by Stephenson) in July, 1970. Figure 1 shows the locations of these wells as well as those already present in the area. All test holes were drilled to 3 meters or greater below the water table elevation found on the date of drilling. Sand point piezometers (3.21 cm diameter) were installed in each test hole to provide a continuing capability for measuring the groundwater evaluation.

In an effort to evaluate potential phosphate transport in the development area several preliminary sorption tests were run on area soil samples provided by Owen Ayres & Associates. Analyses were made by taking approximately two grams of the sample provided, placing it in a 300 ml flask to which 100 ml of a 10 mg P/l solution was added. Each flask was capped and shaken for 24 hours. At the end of this period, each sample was filtered through a 0.45 micron pore size membrane filter that had been pre-washed with distilled water. The phosphate content of the filtered solution was determined by the phosphomolybdate method (APHA et al., 1965). Blanks were carried through the tests to compensate for losses due to sorption of phosphorus on glass during filtration, etc. The amount of phosphate lost to the sand was determined by subtracting the phosphate concentration remaining in the solution after contact with the sand from the initial phosphate solution added to the sandy mixture. The phosphate sorbed per gram of sand was determined by dividing the amount of the phosphate uptake by the weight of sand used in the particular study. Each sample was run in duplicate.

Figure 1
Location of Hydrologic Test Wells
Voyager Village Development Area
Scale: 1cm = 0.6 km



After Stephenson (1971).

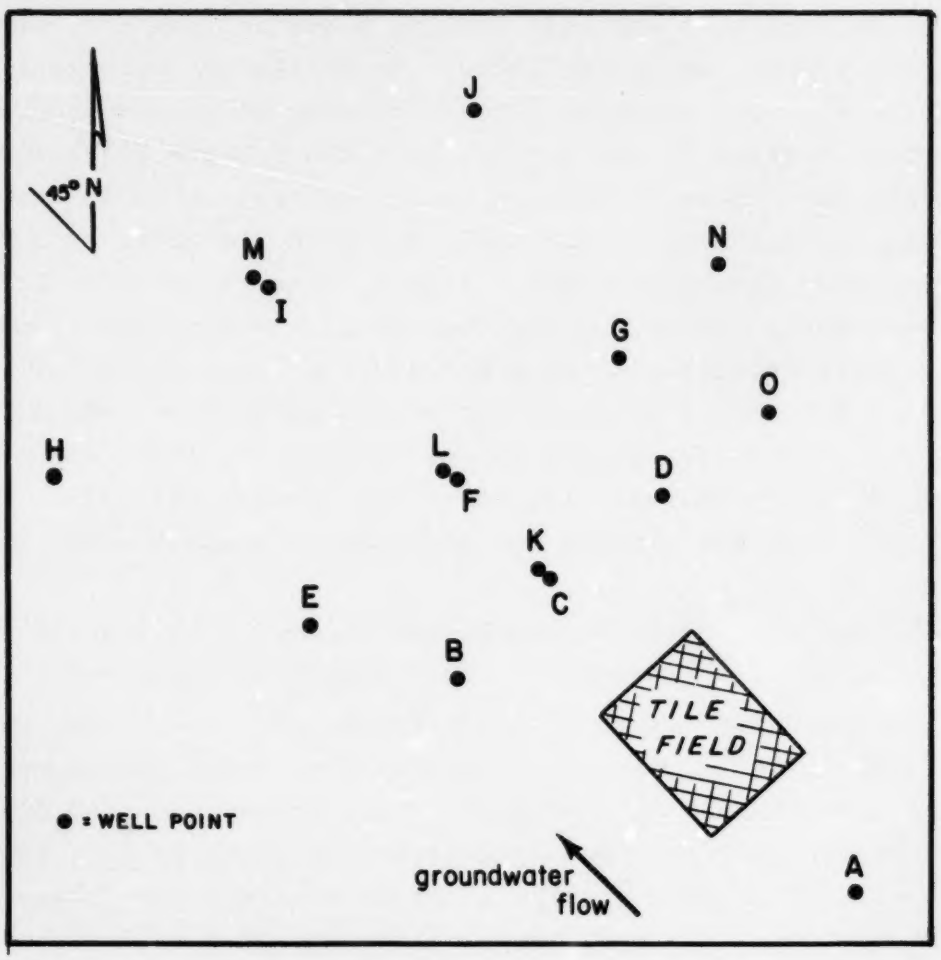
To obtain an estimate of the surface water quality at the outset of the study, grab samples were collected from lakes and streams in the area on June 9, 1970. About a month later, selected wells shown in Figure 1 also were sampled. Phosphate analyses were carried out in accordance with the phosphomolybdate method (APHA et al., 1965).

After the direction and general velocity of the groundwater had been defined by Stephenson (1971), a septic tank effluent monitoring program was established. An existing septic tank system in the vicinity of wells 3 to 7 (an area to be serviced by septic tank systems in conjunction with the Voyager Village development) was chosen for monitoring. Observation wells were placed as shown in Figure 2. Wells A-J were installed at a depth of 1.5 m below the water table; wells K, L and M to 4.6 m below the water table. Later, during the study, two additional wells, N and O, were drilled also to a point 1.5 m below the water table.

Wells A-M were sampled on the following dates: February 3, February 16, April 17, August 29 and October 29, 1972; January 25 and July 26, 1973; October 10, 1974; and January 15, 1976. On October 10, 1974 and January 15, 1976, wells N and O were also sampled.

Although the analysis program was occasionally altered during the course of the study, the following parameters were generally measured: specific conductance, pH, alkalinity, Na^+, Cl^-, K^+, Mg^{++}, Ca^{++}, soluble orthophosphate, total phosphorus, NH_4^+, NO_3^-, and organic N. Phosphate analyses were carried out in accordance with the phosphomolybdate method (APHA et al., 1965; APHA et al., 1971; APHA et al., 1976) or equivalent. Elevated chloride and specific conductance values are good indicators of the presence and movement of septic tank effluent in groundwater. The alkalinity, calcium and magnesium concentrations can provide general information regarding direction of effluent flow in the groundwater but are usually not as useful as chloride and specific conductance values in this regard. The sodium concentrations should generally follow the chloride concentrations although they

Figure 2
Test Wells for Septic Tank
Monitoring Study
Voyager Village Development Site
Scale: 1cm = 7.6 m



After Huff and Stephenson (1971).

are not usually as sensitive to changes in concentrations resulting from contamination by septic tank effluent. The potassium and sulfate values are useful in this study only in terms of characterizing the general content of the groundwater. Neither measurement can be interpreted in a way as to contribute to the overall objectives of this study. Turbidity can give an indication of the amount of suspended solids not purged from the well prior to sample collection.

As the focus of this study is on the transport of aquatic plant nutrients, especially phosphorus, of primary interest are the concentrations of soluble orthophosphate, nitrate and ammonium. Total P and organic N concentrations have little meaning in this groundwater study as they do not give an indication of available forms of aquatic plant nutrients that are allowed to pass through the groundwater to potentially influence surface water quality.

CLIMATE

According to Blackman et al. (1966), the climate of the area (Burnett County, located in northwest Wisconsin) is continental. Mean temperatures drop below freezing in mid-November and freezing of lakes follows soon after. The average date of the first freeze in the fall is September 12; the average last freeze in spring is May 31. The average annual precipitation for Burnett County is about 78 cm. The average runoff is 24 cm near Rush City on the St. Croix River. Maximum precipitation occurs in June; however, highest runoff usually occurs during April in association with snowmelt.

The original vegetation of the southern farm area in the southern part of the county was oak or pine, but the second growth timber is largely white birch and aspen.

QUALITATIVE DESCRIPTION OF SOILS AND GEOLOGY

N.E. Isaacson & Associates, Inc. began an investigation of the hydrologic and hydrogeologic characteristics of the Voyager Village development area in April, 1970. These studies were

conducted by Stephenson (1971) and Huff and Stephenson (1971). They found that stratified sandy soil deposits, mostly glacial drift outwash, characterized the area. The deposits were products of glacial melt-water stream deposition which occurred in recent geologic time. Deposits of the last glacial episode were subsequently covered by younger outwash containing large, melting ice blocks. The hummocky topography of the area was created as the buried ice blocks melted.

The glacial drift deposits are a fine to medium grained sand; mean grain size diameter was 0.125 to 0.5 mm. The sand deposits could generally be vertically zoned into two rather distinct and recurring units:

1. Sand: dark red brown; fine- to medium-grained; sometimes silty; generally 3 to 9 m thick; permeability ranges from 0.4 to 1.2 $l/cm^2/day$.

-overlying-

2. Sand: light red brown; medium- to coarse-grained; permeability ranges from 1.2 to 4 $l/cm^2/day$; thickness unknown but estimated at maximum of 46 m.

Stephenson (1971) indicated that these layers likely overlaid a crystalline bedrock composed of granite-like Precambrian rocks.

Table 1 presents representative grain size characteristics for selected and representative samples taken at or near the water table elevation within three of the wells. The predominant sand grain size at or near the water table was within the medium grain range, 0.25 to 0.5 mm diameter. The water table occurred in either of the two vertical soil zones described, depending on the location within the development area. According to Huff and Stephenson (1971) the water table was generally within the upper, finer-grained soil east of Shoal and Cadotte Lakes and within the lower, coarser-grained sands west of that position. They attributed this to the coincidence of the mean water table level in the Shoal and Cadotte Lakes are (299-300 m elevation) with the average elevation of the fine/coarse-grained sand boundary (299 ± 1.5 m elevation).

TABLE 1

SIEVE ANALYSES ON SELECTED SAMPLES-VOYAGER VILLAGE, BURNETT COUNTY

Sieve Size	Well No. 2		Well No. 3		Well No. 6	
	Weight gms	Percent Total	Weight gms	Percent Total	Weight gms	Percent Total
10 mesh (2 mm)*	28	1.31	27	1.27	--	--
16 mesh (1.2 mm)	228	10.63	219	10.34	0.5	0.05
40 mesh (0.42 mm)	820	38.29	1240	58.52	17	1.60
60 mesh (0.25 mm)	788	36.74	379	17.89	375	35.34
80 mesh (0.15 mm)	185	8.62	153	7.22	489	46.09
<80 mesh (0.15 mm)	96	4.48	101	4.77	179	16.87
TOTALS	2145	100.07	2119	100.01	1061	99.95

*Wentworth Scale for sand:

very coarse-grained	1.0 - 2.0 mm
coarse-grained	0.5 - 1.0 mm
medium-grained	0.25 - 0.5 mm
fine-grained	0.125 - 0.25 mm
very fine-grained	0.0625 - 0.125 mm

Dash (--) indicates no contribution made from that fraction.

Stephenson (1971) noted a soil composition change which occurred along the approximate line A-A' shown in Figure 1. Northeast of this line, soils were sandy as previously described. To the southwest, the soil matrix was siltier; however, gravel percentages were found to increase. Gravel was scarce over much of the northeastern area. According to Stephenson, there appeared to have been a relationship between the soil differences and differences in surface water character; Bartash Lake had soft water and was non-calcareous. The surface waters to the northeast appeared to be hard waters.

SORPTION TESTS

The results of phosphate sorption tests run on the soils of the study area are presented in Table 2. Examination of this data shows that the various samples sorbed from 1 to 5 mg P/100 g soil in 24 hours. This amount of sorption is small when compared to what would be expected in typical clay soils. Various clay mineral soils have been found to sorb, at neutral pH, from 0.03 to 0.07 millimoles phosphorus per gram solid (93 to 217 mg P/100 g solid) at equilibrium (Grim, 1953). Although the behavior of various types of natural soils from other areas under the particular test conditions used was not generally known, the results of the Voyager Village development area soil tests tended to show low short-term sorption capacity. However, tests of this type do not adequately measure long-term sorption and precipitation such as that associated with hydroxyapatite formation. Comparison of the sorption values with the sorption maxima reported in Tofflemire et al. (1973) and Ellis and Erickson (1969a) shows that the amounts of P sorbed by these samples (1 to 5 mg P/100 g) were at the lower end of the range of maximum sorption reported in the literature (2 to 49 mg P/100 g). If higher concentrations had been incorporated in this testing, it is likely that greater sorption capacity would have been found.

TABLE 2

PHOSPHATE SORPTION TESTS ON THE

VOYAGER VILLAGE DEVELOPMENT AREA SOIL

(sorption time - 24 hours)

Well Number*	mg P/100 g solid
6	2.2
6	1.2
9	4.0
9	4.3
17	3.4
17	1.9
18	4.0
18	3.1
24	2.8
24	2.1
38	3.4
38	5.0

*Numbers do not necessarily correspond to well numbers.

Samples provided by Owen Ayres & Associates.

HYDROLOGY AND WATER QUALITY

Available water table and surface water elevations for October, 1970 as presented by Stephenson (1971) are shown in Figure 3 and indicate that the groundwater in the Voyager Village development area moved from the southeast to the northwest. According to Stephenson (1971) surface water movement was also in this direction, toward the St. Croix River. Estimated permeability values in the sand layers at the wells averaged from 1.2 to 2.4 $l/cm^2/day$ (Huff and Stephenson, 1971). The recharge for the development area groundwater appeared to be southeast of Birch Island Lake.

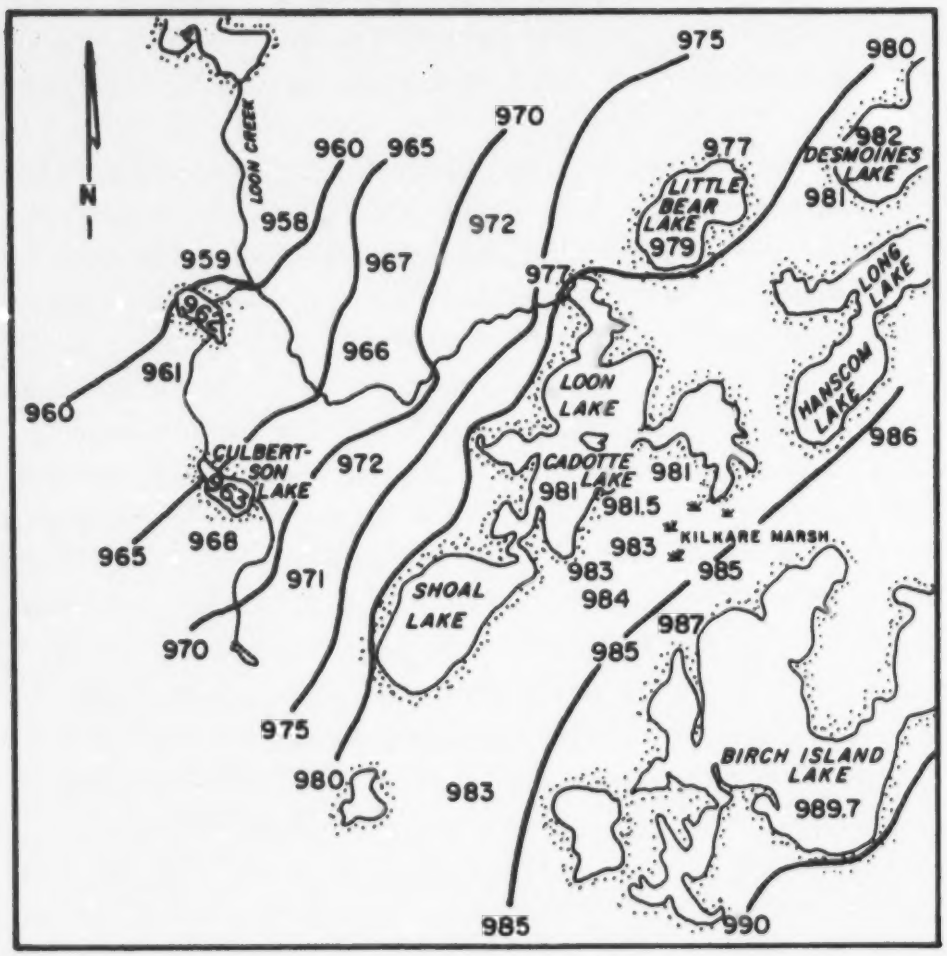
Drainage systems in recently glaciated regions are not always well developed. As a result, according to Huff and Stephenson (1971), perched and/or otherwise isolated surface water bodies are not uncommon. The unnamed lake to the west of well 13 appeared to be perched 7.6 to 9.1 m above the water table. Huff and Stephenson noted that this fact may account for its apparently more advanced eutrophic state relative to other area lakes.

In general, groundwater in the development area was found to move in a simple flow pattern. The surface topography of the area apparently had no influence on the direction of groundwater movement. According to Huff and Stephenson (1971), this appeared to be true both for the different seasons and for different conditions. For most, if not all lakes within the Voyager Village development boundaries, groundwater entered lakes from the east and southeast perimeter and re-entered the groundwater system along the west and northwest perimeters of the lakes.

Groundwater Velocity

As discussed by Stephenson (1971), the water table gradient for that portion of the development area between Birch Island and Shoal-Cadotte Lakes would be one m per 1000 m. An estimate of groundwater flow volume per m width of flow path in 46 m of soil was between 242 and 2019 l/day. The 242 l/day estimate was for the development between Birch Island and Shoal-Cadotte Lakes. Groundwater velocities were calculated to range from 0.15 to

Figure 3
Groundwater Flow Pattern
Voyager Village Development Site
Water Table Elevations on October 17 and 21, 1970
Lake Surface Elevations on October 3, 1970
(Elevations in Feet Above Mean Sea Level)
Scale: 1cm = 0.6km



After Stephenson (1971).

Note: The units in this figure were taken from the original report (Stephenson, 1971).

1.2 m/day. In the area of immediate interest where the septic tank study was conducted, a velocity of about 0.3 m/day appeared to be average.

Groundwater Quality

The 21 wells were sampled once in July, 1970. The values of the various physical and chemical parameters measured are presented in Table 3. The pH of the various groundwater samples ranged from 6.4 to 7.6. pH values in this order of magnitude are normally found in groundwaters and would not cause any water quality problems.

Specific conductance values ranged from 64 to 440 µmhos/cm at 21°C. The majority of the wells had specific conductance values between 100 to 200 µmhos/cm. Specific conductance is a measure of the total amounts of salts in solution. The contamination of groundwaters by septic tank effluents will be expected to increase the total amounts of salts considerably above the levels found in the wells sampled. The high value of 440 for well number 1 is somewhat surprising since wells 2, 3, 4, 7 and 8 are located in the same general area and all show values which are more in accord with what is expected. The examination of well 1 data shows that the calcium and alkalinity are also high for this well, while the chloride is about the same as in the other wells. The sodium is higher for this well than the others. It appears that this well is in an area where the groundwater has had the opportunity to pick up significant amounts of calcium and carbonate species from the detrital limestone in the region.

Generally, turbidity values in groundwaters are low and frequently zero due to the filtration of the particulate matter by the aquifer material. The high turbidity values noted in some of the wells resulted from the large amounts of suspended solids which arose from the recent placement of the well points in the area. In order to make a more realistic assessment of the turbidity levels in the water, it would be necessary to pump each of these wells for a considerable period of time. This would tend to clear up and eliminate the debris that is left in the well

TABLE 3

CHEMICAL ANALYSIS OF THE WELL POINT SAMPLES FROM VOYAGER VILLAGE PROJECT

COLLECTED IN JULY, 1970 BY D.A. STEPHENSON

Parameter*	WELL POINT NUMBER																	
	1	2	3	4	5	6	7	8	10	11A***	11B	13	14	16	18	19	20	21
pH	7.5	6.6	7.5	6.4	7.0	6.9	7.6	6.9	6.7	-	6.9	6.7	7.0	7.2	7.1	7.1	6.9	6.7
Specific Conductance µmhos/cm at 21°C	440	101	751	64	113	265	141	120	91	-	118	97	66	95	220	220	110	97
Turbidity (JTU)	5	0	11	19	0	10	11	0	17	-	-	17	0	16	0	0	8	17
Na^{+}	12	1.6	4.0	1.5	2.0	5.4	3.3	2.3	1.7	-	3.4	3.7	2.0	3.4	7.2	4.3	2.7	4.3
Mg^{++}	15.5	2.5	6.5	2.5	6.0	6.5	5.5	5.0	4.0	-	4.1	3.0	2.5	3.0	7.0	15.5	3.5	3.0
Ca^{++}	50.0	5.5	23.0	3.0	7.0	16.0	12.5	7.0	8.0	-	8.0	5.0	4.0	5.0	19.0	44.0	10.0	5.0
NO_3^{-}-N	0.7	0.15	0.30	0.15	0.08	0.60	0.15	0.07	0.08	1.40	0.17	0.70	1.6	1.0	0.45	0.40	0.15	1.0
NH_4^{+}-N	0.15	0.45	0.60	0.21	0.11	0.02	0.50	0.01	0.03	0.06	0.09	0.12	0.11	0.10	0.06	0.05	0.12	0.30
Total P	0.4	0.34	0.08	0.06	0.02	0.16	0.13	0.30	0.20	0.12	>4	>4	0.16	0.36	0.77	>4	0.24	0.58
Soluble ortho P**	0.007	0.006	0.003	0.001	0.001	0.005	0.005	0.004	0.006	0.08	0.01	0.04	0.005	0.001	0.001	0.013	0.004	0.005
Cl^{-}	3.0	2.5	12.5	2.5	2.5	13.5	5.0	5.0	2.0	-	5.5	3.0	3.5	4.0	15.5	2.0	4.0	4.5
Fe"soluble"**	0.03	0.16	0.01	0.07	0.03	0.03	0.03	0.03	0.11	0.03	0.06	0.4	<0.01	0.03	0.07	0.03	0.13	0.07
Fe total	0.85	0.21	0.23	6.42	2.63	0.47	0.03	0.82	0.98	-	15.1	5.0	1.25	1.40	1.41	0.3	0.23	2.16
Alkalinity as $CaCO_3$	168	38	115	29	59	99	70	45	45	-	62	33	18	33	82	178	52	34

*All values reported as mg/l except pH, Specific Conductance and turbidity.

**Soluble defined as passage through 0.45 µ pore size membrane filter.

***Insufficient sample collected for complete analysis.

Many of the samples collected contained large amounts of suspended solids that arose from the drilling of the well points. These turbidity, total iron and total phosphate values are expected to be much larger than normally found in groundwaters as a result of this contamination.

immediately after placement. No attempt should be made to judge any change in water quality based on changes in turbidity from those reported at this sampling.

The sodium values ranged from 1.5 mg/l to about 12 mg/l with the typical values on the order of 2 to 5 mg/l. These values are normal for groundwaters of the area. The 1970 levels of sodium in the groundwater do not represent any adverse effect on water quality. It would be expected that large increases in the amount of sodium in the groundwaters would occur as a result of the contamination of the aquifer by septic tank effluent.

The magnesium values ranged from 2.5 to 15.5 mg/l. These values indicate that, in general, the aquifer material has a low limestone content and the waters derived from it would be classified as soft waters.

The calcium values ranged from 3 to 50 mg/l. The majority of the values ranged from 3 to 15 mg/l. The only exceptions to these values were well numbers 1 and 19. The high values at well numbers 1 and 19 indicate that these wells are in small pockets of calcareous material. This observation is supported by the fact that these two stations have relatively high alkalinities which indicate that the high calcium arises from the dissolution of calcium carbonate in the aquifer.

Nitrate derived from ammonium is one of the constituents of septic tank effluent which affects groundwaters. All of the nitrate values for the wells sampled were less than 2 mg/l nitrate-N. Concentrations of this magnitude are typically found in groundwaters. Concentrations of 10 mg/l N are considered to be excessive and would cause the water to be rejected for water supply purposes. However, in-lake concentrations in excess of approximately 0.3 mg/l nitrate-N are of concern and would tend to produce excessive growths of algae and aquatic plants in the lake if other constituents necessary for growth were present in adequate amounts. Septic tank effluent will likely lead to increased concentrations of nitrate in groundwaters. This could further aggravate the problems caused by excessive fertilization of lakes

if the septic tank effluent flowed through the groundwater into the lakes, and if the lake system is nitrogen limited. Fortunately, there are a number of chemical and biochemical reactions that tend to reduce nitrate concentrations in some groundwaters. These reactions will tend to minimize the nitrate problems in some areas. However, the understanding of these reactions is such that it is impossible to predict without extensive study whether or not nitrate may be a problem as a result of contamination of groundwaters by septic tank effluent. It appears from Table 4 that a comparison of available nitrogen and phosphorus concentrations shows that nitrogen may be the limiting nutrient in at least some of the area lakes. Therefore, groundwater nitrate may be a problem in influencing algal growth in surface waters.

Generally, groundwaters have very low concentrations of ammonium since this chemical species tends to be sorbed onto soil particles. As indicated by ammonium concentrations in excess of 0.1 mg/l N, the aquifer materials of this area likely have a low sorption capacity for ammonium. The concentrations found in these wells would generally present no significant water quality problems for domestic use. However, when ammonium concentrations in groundwater discharging into a lake are greater than 0.3 mg/l N, a potential for increasing the fertility of the lake exists since ammonium in addition to nitrate is readily available for algal growth.

The total phosphorus concentrations found in these wells are not generally characteristic of the groundwaters since they represent the phosphorus associated with the high turbidity (suspended solids) which resulted from the recent placement of the wells relative to the well sampling. Normally, one would expect to find little total phosphorus in the aquifer and any phosphorus that is found would probably be in a soluble orthophosphate form.

Nearly all the values for soluble orthophosphate are less than the critical levels of 0.01 mg P/l that have frequently been found to cause excessive growths of algae and other waterweeds in lakes. The one exception was well 11A which had been found to

TABLE 4

CHEMICAL ANALYSIS OF SURFACE WATERS IN

VOYAGER VILLAGE DEVELOPMENT AREA

(June 9, 1970)

Parameter	LOCATION				
	Bartash Lake	Outlet Loon Lake	Little Bear Lake	Culbertson Creek-Spring Outlet	Loon Creek at Loon Creek Trail
Specific Conductance µmhos/cm @ 22°C	26	110	100	148	147
pH	7.2	8.8	8.2	9.1	8.1
NH_4^+-N	0.04	0.04	0.04	0.02	0.06
NO_3^--N	< 0.02	0.04	0.04	0.06	0.06
Organic-N	0.52	0.36	0.55	0.3	1.1
Soluble ortho P*	0.006	0.086	0.143	0.098	0.264
Total P	0.032	0.364	0.556	0.408	0.574
Aklalinity as $CaCO_3$	2.2	50.0	48.0	74.3	54.5

*Soluble is defined by passage through a 0.45 µ pore size membrane filter.

All values reported as mg/l except Specific Conductance and pH.

contain 0.08 mg P/l soluble orthophosphate. It is likely that this sample was contaminated as it contained large amounts of suspended solids and there was insufficient liquid available to perform the complete set of analyses on it. Based on the previous studies conducted on the sorption capacity of the aquifer materials from this area, it is reasonable to conclude that surface-water contamination problems could result from the use of septic tank wastewater disposal systems in this area, provided that the contaminated groundwaters reach a lake or stream. Normally, phosphate is not transported to any degree in aquifers which are high in calcium carbonate, due to the interaction of the phosphate with the calcium. Therefore, in the areas where high alkalinity and hardness were noted, lesser phosphate transport will be expected.

The chloride levels found in the various wells ranged from 2 to 15.5 mg/l. These levels would not cause any water quality problems. The discharge of septic tank effluents to groundwaters will result in a large increase in the chloride content of these waters. Chloride is one of the chemical parameters that is a useful indicator of the contamination of groundwaters by septic tank effluents.

The total iron represents the iron that is primarily from the contamination of some of the water samples by the well point driving operations. The soluble iron represents that iron that would pass through a 0.45 micron pore size filter and is probably, in this case, iron that is in a very finely divided particulate form. The iron present may aid in the removal of phosphorus from the effluents.

The alkalinity values ranged from about 30 to 180 mg/l as calcium carbonate. The alkalinity values parallel the calcium and magnesium values. The high alkalinity values reflect the fact that some parts of the aquifer are somewhat calcareous.

From an overall point of view, the groundwaters in the Voyager Village development area were of high quality at the onset of the study.

Surface Water Quality

In order to assess general surface water quality in the Voyager Village development area before development, grab samples of water were collected from the lakes and streams in the area. The values of general physical and chemical parameters measured in the surface waters are presented in Table 4. At the time of year that samples were collected, relatively low concentrations of nitrate, ammonium and soluble orthophosphate will likely be present in surface waters as a result of uptake by aquatic plants. Consideration, therefore, must be given to the total phosphorus and organic nitrogen concentrations. These values reflect to a degree the amounts of potentially available nutrients present within algal cells which would become available upon the death of the plants.

Bartash Lake is a soft water, seepage lake of high water quality. It had a very low specific conductance of 26 µmhos/cm @ 22°C. The alkalinity in this lake was 2.2 mg/l as $CaCO_3$. The aquatic plant nutrient concentrations found on the date of sampling were generally low. The only well drilled near Bartash Lake is number 21. Comparison of the water quality between this well (Table 3) and the lake shows that there was little relationship between the two. Water taken from well 21 had a much greater alkalinity and greater specific conductance than that of the lake.

Loon Lake is a hardwater seepage lake adjoining Cadotte Lake. The north end of the lake on the date of sampling had thick, aquatic vegetation and a few areas of floating bog. Based on the high pH and high total P concentration, it would appear that on the date of sampling, this was a highly productive lake. The wells located near Cadotte and Loon Lakes (Table 3) had alkalinity and specific conductance values which were similar to, although not the same as, the lake water.

Little Bear Lake is a hardwater seepage lake containing high concentrations of phosphorus and a relatively high organic N concentration. This would indicate a fertile water body. Well 20, located on the north side of the lake, had a general chemical com-

position similar to that of the lake. This would be expected since this well was in the general direction of groundwater flow.

Culbertson Creek appeared to be a hardwater stream containing relatively high concentrations of aquatic plant nutrients. Wells 13 and 19 in the Culbertson Creek area had respectively lower and higher specific conductance and alkalinity than the creek. Look Creek at Look Creek Trail is a hardwater stream containing the highest concentrations of both nitrogen and phosphorus compounds of the lakes and streams sampled.

From an overall point of view, except for Bartash Lake, all of the other lakes and streams in the development area seemed to be experiencing excessive aquatic plant fertilization in the absence of any development in the area.

SECTION 5

RESULTS

SEPTIC TANK USE

The septic tank-tile field wastewater disposal system monitored for this part of the study went into operation on May 20, 1971 serving a middle-aged couple. This couple resided on the property for nine months each year during the spring, summer and fall. They used an automatic washer with cold water All detergent. There was no garbage disposal in use, but a dishwasher was installed in May, 1973 (Carlson, 1973).

OBSERVATION WELL MONITORING

The first water samples were collected from wells A-M (see Figure 2) on February 3, 1972. The results of the analyses made on these samples are presented in Table 5. Slightly higher chloride values were found at several wells (I, J, L, M), but not at wells immediately down groundwater gradient from the tile field. This pattern appeared to be related both to the fact that the residence was not occupied during the winter months and that the septic tank had been installed only eight months prior to sampling. Of the four wells that showed elevated Cl^- concentrations, two of them were the deeper wells. Higher calcium concentrations were found in the deeper wells and could generally be related to higher alkalinity values there. In these measurements, as well as subsequent measurements, elevated concentrations of alkalinity and, in many cases, calcium were observed in wells directly down groundwater gradient from the tile field. In some instances, such as on the February 3 sampling, and in some subsequent samplings, the increased alkalinity and calcium were not accompanied by an increase in chloride. However, increases in

TABLE 5

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(February 3, 1972)

Parameter	WELL POINT A	B	C	D	E	F	G	H	I	J	K	L	M
Specific Conductance μmhos/cm @ 20°C	48	55	59	47	45	60	48.5	48.5	53	40	54	68	56
pH	6.2	6.5	6.7	6.7	6.8	6.8	6.6	6.7	6.8	6.6	6.8	6.8	6.9
Cl^-	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.1	1.4	0.5	1.1	1.1
Na^+	1.3	1.4	1.4	1.2	1.2	2.1	1.2	1.2	1.6	0.9	1.2	1.2	1.4
K^+	0.5	0.5	0.5	0.5	0.7	0.6	0.5	0.6	0.5	0.5	0.6	0.7	0.6
Ca^{++}	4.7	5.0	4.7	4.8	5.0	7.5	4.6	4.9	6.2	4.6	6.1	8.5	6.8
Mg^{++}	1.8	1.7	0.5	2.2	2.0	1.4	3.4	2.3	2.3	3.2	2.6	2.9	2.5
Alkalinity as $CaCO_3$	13.8	18.8	21.4	14.0	14.6	21.3	11.7	14.1	18.1	10.3	18.0	27.6	20.6
$SO_4^=$	13.0	12.0	13.0	13.7	15.0	13.4	15.0	12.7	16.4	14.7	11.0	8.3	12.2
Soluble ortho P	0.011	0.017	0.016	0.015	0.013	0.015	0.013	0.017	0.021	0.013	0.009	0.014	0.019
Total P	0.13	0.067	0.058	0.088	0.23	0.17	0.11	0.16	0.18	0.36	0.077	0.049	0.13
NH_4^+-N	0.065	--	--	--	--	--	0.059	<0.05	0.054	--	--	--	0.05
NO_3^--N	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Organic N-N	0.20	0.10	0.12	0.20	0.23	0.23	0.09	0.12	0.20	0.09	0.08	0.10	0.23

All values mg/l unless otherwise stated.

Dash (--) indicates analysis not made.

specific conductance were noted. It appears that the septic tank effluent was causing dissolution of calcium carbonate or contained elevated calcium and bicarbonate concentrations. The soluble orthophosphate concentrations were about the same both up and down groundwater gradient from the tile field as were concentrations of ammonium and nitrate. Neither total P nor organic N concentrations showed evidence of contributions from septic tank effluent. The concentrations immediately down groundwater gradient from the tile field were slightly lower than those upgradient.

The observation wells were sampled February 16, 1972, two weeks after the first sampling. The data are presented in Table 6. In general, the pH values were somewhat lower and the soluble ortho P values were consistently three to five times lower than those values found during the previous sampling. The specific conductance, sodium and alkalinity values showed that septic tank effluent had migrated as far as well F. The calcium concentration was greater in the deeper wells than in many of the more shallow ones and roughly corresponded to the alkalinity values which were generally greatest in the deeper wells. None of the available forms of aquatic plant nutrients (soluble ortho P, nitrate, ammonium), total P or organic N showed an increase in concentration down groundwater gradient from the septic tank tile field. Organic N values were all slightly lower down groundwater gradient from the tile field than upgradient.

Table 7 presents data from the well sampling on April 17, 1972, two months after the previous sampling. The specific conductance values appeared to be somewhat greater down groundwater gradient from the tile field than the value upgradient. The greatest specific conductance values were found in the deeper wells and indicated the possibility of effluent movement in the groundwater. The pH values were generally one unit above what they had been at the last sampling. The calcium concentrations appeared to be highest in the wells directly down groundwater

TABLE 6

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(February 16, 1972)

Parameter	WELL POINT												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Specific Conductance μmhos/cm @ 20°C	52	55	63	50	45	73	58	40	56	39	56	73	55
pH	6.2	6.2	6.2	6.0	6.0	6.2	6.1	6.3	6.0	6.1	6.4	6.6	6.3
Cl^-	2.3	2.3	2.3	1.8	1.8	1.2	0.6	1.8	1.8	1.2	2.3	1.8	1.8
Na^+	1.2	2.1	2.4	1.8	1.4	2.2	1.8	1.5	2.3	2.1	1.9	2.0	2.1
K^+	1.1	0.8	0.8	0.2	0.6	1.1	0.8	0.8	0.2	0.4	0.8	0.8	0.9
Ca^{++}	4.8	6.9	5.9	4.5	4.5	10.1	5.4	3.7	5.2	3.1	5.8	9.2	6.0
Mg^{++}	2.8	0.7	3.2	2.8	2.4	1.4	1.4	2.2	3.6	2.4	3.2	2.8	2.3
Alkalinity as $CaCO_3$	13.5	18.0	22.5	15.0	13.5	21.0	15.0	13.5	13.5	10.5	28.5	31.5	21.0
$SO_4^=$	12	10	10	10	9	9	18	7	10	9	9	8	8
Soluble ortho P	0.005	0.004	0.004	0.005	0.004	0.006	0.004	0.004	0.006	0.004	0.004	0.008	0.007
Total P	0.02	0.019	0.019	0.034	0.016	0.064	0.062	0.024	0.079	0.025	0.016	0.012	0.011
NH_4^--N	0.04	0.06	0.05	0.08	--	0.08	0.05	0.04	0.08	0.06	0.04	0.06	0.04
NO_3^--N	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Organic N-N	0.21	0.09	0.16	0.10	0.12	0.20	0.16	0.18	0.09	0.12	0.16	0.16	0.18

All values mg/l unless otherwise stated.

Dash (--) indicates no analysis made.

TABLE 7

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(April 17, 1972)

Parameter	WELL POINT A	B	C	D	E	F	G	H	I	J	K	L	M
Specific Conductance µmhos/cm @ 20°C	52	69	69	60	50	74	50	40	69	42	80	76	58
pH	7.4	7.6	7.5	7.4	7.4	8.2	7.4	7.5	7.6	7.5	7.5	7.7	7.6
Cl^-	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Na^+	2.1	2.0	2.0	1.8	1.5	2.4	1.8	1.5	2.0	1.2	2.2	2.0	1.8
K^+	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4
Ca^{++}	5.6	6.6	7.7	6.5	5.2	6.5	5.5	4.0	8.1	3.9	9.5	8.3	6.4
Mg^{++}	2.2	1.7	2.2	2.7	3.0	3.5	2.8	2.8	3.0	2.4	0.7	4.9	3.2
Alkalinity as $CaCO_3$	15	51	27	16	18	21	12	16	26	12	21	34	21
$SO_4^=$	11.1	10.9	8.3	11.1	9.3	9.1	10.9	5.3	8.6	9.5	7.7	8.8	6.9
Soluble ortho P	0.008	0.006	0.006	0.009	0.003	0.009	0.006	0.003	0.008	0.006	0.004	0.005	0.003
Total P	0.09	0.08	0.08	0.09	0.05	0.17	0.08	0.04	0.06	0.12	0.05	0.12	0.02
NH_4^+-N	0.23	0.16	0.12	0.16	0.14	0.13	0.36	0.18	0.24	0.22	0.34	0.13	0.17
NO_3^--N	0.12	0.1	0.07	0.11	0.10	0.11	0.09	0.10	0.09	0.10	0.17	0.10	0.07

All values mg/l unless otherwise stated.

gradient from the tile field and also in the deeper wells (K and L). None of the aquatic plant nutrients appeared to be transported from the septic tank effluent through the groundwater at this sampling.

The data from samples collected on August 29, 1972 (Table 8), indicate that septic tank effluent was moving in the direction of estimated groundwater flow. The specific conductance, chloride, calcium, alkalinity and nitrate levels all appeared to be greater at well points C and F, directly down groundwater gradient from the septic tank tile field, than those at outlying or upgradient wells. Potassium concentrations varied between 2 and 5.4 mg/l without an apparent pattern. The soluble orthophosphate, total phosphorus and ammonium concentrations did not reflect effluent contamination, however. Those values at wells down groundwater gradient from the tile field were generally the same or less than values upgradient.

Table 9 presents the data from groundwater samples collected on October 29, 1972. Since the fall of 1972 had been a particularly wet period, the concentrations of some of the parameters may be markedly different from those which would normally be encountered in shallow groundwater. The specific conductance and alkalinity both showed evidence of effluent contamination of the first tier of wells, the three deeper wells, and as far directly down groundwater gradient as well points I and M. The soluble orthophosphate concentrations were greater on this date than on most of the previous dates. This could be related to the high rainfall received that fall. The down groundwater gradient concentrations were, however, about the same or less than the concentration above the tile field. Total phosphorus, ammonium, and nitrate from septic tank effluent did not appear to be contaminating the groundwater. The groundwater turbidity was high in samples from wells A and F, possibly indicating suspension of sediment in the well during sampling.

On January 25, 1973, wells A-M were sampled. Selected samples were analyzed for only selected constituents as presented

TABLE 8

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(August 29, 1972)

Parameter	WELL POINT A	B	C	D	E	F	G	H	I	J	K	L	M
Specific Conductance µmhos/cm @ 20°C	52	40	68	56	48	64	51	41	57	42	60	40	88
pH	6.5	5.7	6.8	6.9	7.5	7.0	6.6	6.7	7.5	7.0	7.0	6.9	7.0
Cl^-	2.3	1.6	4.1	1.5	1.5	2.7	2.8	1.8	3.3	1.8	2.1	1.8	1.3
Na^+	2.1	2.1	2.2	2.0	1.6	2.3	1.9	1.6	2.2	2.0	1.9	1.5	2.1
Ca^{++}	5.7	15.0	8.0	5.7	3.5	8.5	5.3	4.0	6.3	8.2	8.2	3.2	6.1
Mg^{++}	2.5	3.5	3.0	4.1	0.00	1.1	1.1	0.8	0.1	1.8	1.9	0.2	0.6
Alkalinity as $CaCO_3$	14.4	21.2	24.8	17.4	15.4	23.2	14.0	15.0	17.8	30.0	22.8	10.4	20.0
$SC_4^=$	6.8	11.0	11.2	8.5	10.5	11.5	11.0	5.8	11.7	7.8	7.5	11.7	10.0
Soluble ortho P	0.060	0.006	0.001	0.003	0.005	0.005	0.003	0.004	0.008	0.002	0.002	0.004	0.002
Total P	0.088	0.021	0.013	0.016	0.020	0.022	0.021	0.022	0.056	0.014	0.014	0.030	0.011
NH_4^+-N	0.20	0.23	0.20	0.17	0.26	0.34	0.20	0.14	0.20	0.30	0.16	0.28	0.030
NO_3^- -N	<0.05	0.05	0.13	<0.05	0.06	0.09	0.06	0.06	0.17	0.06	<0.05	0.10	<0.05

All values mg/l unless otherwise stated.

TABLE 9

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(October 29, 1972)

Parameter	WELL POINT A	B	C	D	E	F	G	H	I	J	K	L	M
Specific Conductance µmhos/cm @ 20°C	46	62	130	59	44	63	53	39	56	35	66	70	56
pH	5.8	6.4	6.5	6.7	6.0	6.3	6.7	6.8	6.8	6.9	6.9	7.0	7.1
Turbidity (NTU)	11.4	5.7	2.7	5.4	3.7	13.4	1.9	4.0	3.7	4.3	4.3	2.0	1.6
Cl^-	16.7	12.8	20.8	15.8	11.9	11.9	12.1	25.0	14.1	12.6	17.3	14.9	18.3
Na^+	1.7	20.0	2.6	1.5	1.0	1.9	1.2	1.1	2.0	0.5	1.6	1.7	1.7
K^+	3.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ca^{++}	9.6	7.4	13.4	5.6	5.4	6.7	6.1	4.0	5.8	3.8	8.0	9.1	11.2
Mg^{++}	1.9	2.4	6.1	2.4	1.3	1.3	1.8	1.3	2.0	1.1	2.7	3.1	2.2
Alkalinity as $CaCO_3$	11.6	22.0	31.6	15.4	13.5	21.2	14.3	21.2	23.2	13.5	33.6	31.3	21.6
$SO_4^=$	6.8	4.8	5.5	5.4	5.0	4.4	4.6	2.6	3.0	3.4	3.4	3.0	3.0
Soluble ortho P	0.045	0.006	0.005	0.041	0.020	0.012	0.048	0.038	0.063	0.036	0.040	0.045	0.060
Total P	0.07	0.04	0.04	0.08	0.04	0.09	0.05	0.05	0.06	0.06	0.08	0.10	0.06
NH_4^+-N	0.30	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
NO_3^--N	0.23	<0.04	<0.04	<0.04	0.48	0.17	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

All values mg/l unless otherwise stated.

in Table 10. The specific conductance values indicated the presence of septic tank effluent in the first tier of wells and at least as far down groundwater gradient as wells F and L. Higher chloride and nitrate concentrations were also found at well C, but not beyond that point. There was no detectable movement of soluble orthophosphate or ammonium from the effluent into the groundwater at these wells.

The values of the parameters measured in the groundwater samples collected on July 26, 1973, are presented in Table 11. It appeared that most of the transport of effluent occurred down the central groundwater flow line. Increased levels of chloride and nitrate were found at well C; increased specific conductance was found in the first tier of wells and as far down groundwater gradient as well I. No transport of phosphorus was evidenced by this sampling. As illustrated by the specific conductance, chloride and nitrate values, there appeared to be effluent movement to the right of the central, down groundwater gradient line established. Water from well D showed higher concentrations of these constituents than did water from well B on the opposite side of the center line of groundwater flow as estimated by Huff and Stephenson (1971). The specific conductance value was even slightly above background levels at well G, beyond well D. If the direction of flow had changed from that originally estimated, then additional transport may be occurring which would not have been found at the wells monitored. Therefore, it was decided at this point in the monitoring program to drill two additional wells, N and O, about 15 m northwest (perpendicular to estimated groundwater flow direction) of wells G and D, respectively.

Table 12 presents data from the analyses of selected groundwater samples collected on October 10, 1974. The specific conductance, chloride, calcium, magnesium, nitrate and total kjeldahl nitrogen values all indicated that the direction of the effluent movement appeared to be toward well D as well as down the center (estimated) groundwater flow line. This pattern had been suggested by the data from the previous sampling 14 months earlier.

TABLE 10

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(January 25, 1973)

Well Point	Specific Conductance µmhos/cm at 20°C	pH	Ammonia mg/l N	Chloride mg/l	Sodium mg/l	Soluble ortho phosphate mg/l P	Nitrate mg/l N
A	53	6.3	< 0.1	0.7	1.4	< 0.003	< 0.01
B	74	6.5	< 0.1	< 1.0	1.6	< 0.003	< 0.01
C	96	6.3	< 0.1	3.0	1.8	< 0.003	0.5
D	69	6.6	< 0.1	0.8	1.4	< 0.003	0.01
F	75	-	-	0.9	2.1	0.003	-
K	75	6.5	< 0.1	0.5	1.4	< 0.003	0.01
L	74	-	-	0.7	1.7	< 0.010	-

Dash (-) indicates no analysis made.

Samples were analyzed by WARF Institute, Inc., Madison, Wisconsin

TABLE 11

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(July 26, 1973)

Well Point	Specific Conductance µmhos/cm at 20°C	pH	Chloride mg/l	Sodium mg/l	Soluble ortho phosphate mg/l P	Nitrate mg/l N
A	48	6.0	0.7	1.3	< 0.01	< 0.02
B	71	6.1	0.5	1.8	< 0.01	< 0.02
C	94	6.7	3.5	1.9	< 0.01	0.81
D	89	6.8	2.3	1.5	< 0.01	0.11
E	53	6.2	0.6	1.0	< 0.01	< 0.02
F	84	6.3	1.3	1.9	< 0.01	0.11
G	64	6.0	0.7	1.2	< 0.01	< 0.02
H	45	6.2	0.5	1.0	< 0.01	< 0.02
I	68	6.3	0.7	1.6	< 0.01	< 0.02
J	42	6.2	0.5	0.6	< 0.01	< 0.02
K	65	6.6	0.6	1.4	< 0.01	< 0.02
L	72	6.7	0.5	1.4	< 0.01	< 0.02
M	54	6.5	0.6	1.4	< 0.01	< 0.02

Samples were analyzed by WARF Institute, Inc., Madison, Wisconsin

TABLE 12

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(October 10, 1974)

Parameter	WELL POINT A	B	C	D	E	F	G	H	I	J	K	N	O
Specific Conductance μmhos/cm @ 20°C	53	73	88	245	50	82	59	42	70	44	58	52	53
pH	6.4	6.5	6.6	6.4	6.8	6.7	6.8	6.7	6.8	6.8	6.8	6.8	6.6
Cl^-	0.99	1.14	2.48	25.3	0.89	2.48	1.24	0.84	1.74	0.99	0.99	0.99	0.74
Na^+	3.34	3.64	3.87	4.16	4.46	4.24	3.27	3.12	3.19	2.16	2.82	2.71	3.34
K^+	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ca^{++}	5.10	7.11	9.32	21.5	<5.0	7.61	5.56	<5.0	7.02	<5.0	5.6	5.27	5.23
Mg^{++}	1.58	2.11	2.86	8.33	1.5	2.23	1.67	1.29	2.23	1.11	1.79	1.67	1.91
Alkalinity as $CaCO_3$	15.4	22.0	30.8	22.8	17.6	26.4	15.4	15.4	22.0	13.2	22.0	15.4	17.6
$SO_4^=$	10	14	10	15	12	10	12	4	9	10	8	14	20
Soluble ortho P	0.004	0.005	0.005	0.004	0.002	0.003	0.003	0.006	0.004	0.005	0.004	0.014	0.019
Total P	0.008	0.010	0.012	0.006	0.007	0.010	0.008	0.027	0.011	0.016	0.008	0.034	0.032
NO_3^--N	0.22	0.23	<0.20	0.72	<0.20	<0.20	<0.20	0.20	0.20	0.20	<0.20	0.47	0.41
Total Kjeldahl Nitrogen	0.03	0.07	0.50	11.6	0.07	0.06	0.01	0.01	0.03	0.01	0.01	0.04	0.03

All values mg/l unless othewise stated.

Samples were analyzed by WARF Institute, Inc., Madison, Wisconsin

The increased concentrations found at well D had not yet appeared at wells beyond that point. However, specific conductance, chloride, calcium, and alkalinity values were above background levels all the way down the central groundwater flow line to well I. The total P and more significantly, the soluble ortho P concentrations showed that there had been no phosphate transport from the septic tank tile field to the groundwater. The higher concentrations of both total and soluble ortho P found at the wells N and O were possibly due to sample contamination resulting from the newness of these well points. It is unlikely that they were due to septic tank effluent contamination since concentrations at wells D and G were low.

The last set of samples were collected at the septic tank monitoring site on January 15, 1976, fifteen months after the previous samples were collected. The values of selected parameters measured are presented in Table 13. The highest specific conductance value was found at well D; the value was also high at well G, beyond well D. The highest chloride and sodium concentrations were also found at well D. There was evidence of chloride contamination beyond that point, at both wells G and N. Elevated specific conductance and chloride values were found along the central groundwater flow direction to well I. The deeper wells along that path (K, L, and M), however, did not show increased concentrations of chloride. The pH values of wells B and E were considerably greater than the rest of the wells sampled. Neither total phosphorus nor soluble orthophosphate concentrations showed evidence of phosphate transport in the groundwater downgradient from this septic tank wastewater disposal system.

TABLE 13

VOYAGER VILLAGE SEPTIC TANK MONITORING STUDY OBSERVATION WELL DATA

(January 15, 1976)

Parameter	WELL POINT A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Specific Conductance µmhos/cm @ 22°C	65	35.5	73.5	195	39.5	82.5	81	41.2	79.8	45.5	64.5	85	66	58	49
pH	7.7	9.2	7.8	7.8	9.3	7.8	7.6	7.1	7.7	7.5	7.7	7.9	7.7	7.5	7.5
Cl^-	0.8	0.2	1.6	33.0	0.3	2.8	6.2	0.6	3.0	0.5	0.6	0.6	0.7	2.1	0.8
Na^+	2.0	0.8	2.2	3.4	0.9	2.2	2.0	1.4	2.1	1.1	1.7	1.8	1.5	1.4	1.4
Soluble ortho P	0.005	0.008	0.008	0.008	0.006	0.01	0.008	0.008	0.009	0.006	0.01	0.011	0.01	0.009	0.009
Total P	0.32	0.26	0.31	0.25	0.18	0.28	0.14	0.30	0.30	0.36	0.28	0.20	0.32	0.38	0.32

All values mg/l unless otherwise stated.

SECTION 6
DISCUSSION

Examination of data for the four-year monitoring study shows that septic tank effluent did migrate from the tile field into the groundwaters of the region. This conclusion was based on the data for conservative or essentially conservative chemical tracers such as specific conductance and chloride, and other parameters which may not be conservative. Data collected during this study showed occasionally elevated nitrate and ammonium concentrations in certain wells, but it did appear that there was appreciable nitrogen removed in this aquifer system. No evidence for phosphate transport from septic tank effluent was found in any of the monitoring wells, even though this was a sand aquifer with a relatively high groundwater velocity. Except for the first sampling, there appeared to be no seasonal effects on chemical constituents at the monitoring wells which could be traced to the nine month per year occupancy of the household.

The potential for adverse effects on surface water quality resulting from groundwater transport of aquatic plant nutrients from septic tank wastewater disposal system effluent is controlled by a number of factors. When examining a functioning septic tank wastewater disposal system to determine whether there is a significant contribution to surface water of the phosphorus discharged to the system from a household, it is necessary first to define the groundwater hydrology of the region. Often, as was found in the Voyager Village development area, there is no relationship between surface topography and direction of groundwater flow. Far too often, it is assumed that the hydrology of groundwaters surrounding a lake is such that the direction of the flow is toward the lake. For many lakes, the groundwater flow is in

on one side and out on the other. Those septic tank wastewater disposal systems that are located on the down groundwater gradient side of the lake do not contribute phosphorus or any materials to that particular surface water.

The chemical characteristics both of the unsaturated zone between the tile field and the water table and of the aquifer materials determine to a large extent whether or not aquatic plant nutrients will be transported in the groundwater. Closely associated with this factor is the rate of groundwater flow and the distance between a septic tank system and a water body of concern. Soluble phosphate and ammonium can be sorbed by clay minerals. In addition, phosphate can be sorbed by aluminum and iron oxides, and other minerals in the soil. Phosphate sorption is usually a rapid process, 80 to 90 percent complete in two to five days (Tofflemire et al., 1973). The typically slow movement of groundwater allows for precipitation of soluble phosphate with calcium. The greater the distance the septic tank disposal system is from a water body, the greater the potential for phosphorus removal by the aquifer materials.

It is the chemical composition of the soils rather than grain size characteristics which plays the dominant role in phosphorus removal. Soils in the Voyager Village development area were predominantly fine to medium sands. Even though septic tank effluent was readily measurable in observation wells 60 m downgradient from the septic tank tile field monitored, the sandy aquifer material exhibited complete phosphate removal during the course of the four-year monitoring study.

It is possible that over a period of time, aquifer material sorption sites will become saturated with phosphorus. However, there is essentially infinite capacity for phosphorus removal due to precipitation reactions. Indeed, some investigators have indicated that the capacity for phosphorus removal may be independent of prior exposure to phosphorus.

Another condition affecting potential significance of groundwater transport of aquatic plant nutrients is that there must be

actual recharging of the water body of interest by the groundwater. Especially in glaciated regions, there can exist beneath lakes an impervious clay layer which acts to separate the lake from possible groundwater input. The groundwater then flows beneath or around the lake and no contributions of nutrients or other contaminants to the lake can be made by the groundwater. Some of these so-called perched lakes were found in the Voyager Village development area.

An important factor that should be considered in making a proper assessment of the significance of septic tank wastewater disposal systems as a source of phosphorus for surface waters is the proximity of the septic tank system to the water body of concern with respect to excessive fertilization. For many water bodies, any phosphorus transported from septic tank wastewater disposal system effluent would be contributed to a lake or a stream which is tributary to that water body. As discussed below, a substantial part of this phosphorus never reaches the downstream water body in a form that is available to support algal growth. For almost any lake, there would be on the order of 60 to 90 percent retention of the annual phosphorus load within the lake sediments. This means that for the lake which is ringed by cottages with septic tanks where either the septic tanks have failed or where the subsoil system does not take up the phosphate, while the phosphorus would contribute to the eutrophication problems within the receiving water body, only a small fraction of the phosphorus would actually be transported to downstream water bodies.

An example of this type of situation is the US-Canadian Great Lakes. It would be expected that very little direct phosphate transport due to the utilization of septic tank wastewater disposal systems would be occurring from residences located on the shores of the Great Lakes. Rather, these inputs are generally made to a tributary lake or stream. Little of the P from septic tanks located in the Great Lakes Basin would reach the Great Lakes in an available form to thereby contribute to the excessive fertilization of these water bodies. The basis for this conclusion

is that a large part of the phosphorus present in streams and rivers, especially during periods of high flow, frequently becomes associated with particulate matter where the phosphorus is attached to or becomes incorporated into clay. Further, as available P is utilized in various biological processes, it is becoming less available for stimulation of algal growth since each time it is cycled through a biotic system, some part of the phosphorus becomes refractory. This thereby prevents it from stimulating algal growth. Studies supported by the US EPA conducted by Lee and his graduate students several years ago have shown that much of the particulate phosphorus in several rivers is unavailable for algal growth (Cowen and Lee, 1976). In general, it is likely that available nutrients discharged to rivers which are considerable distances from the lake of interest will have much less influence on stimulating extensive fertilization problems than would the same nutrients discharged directly to the water body.

If aquatic plant nutrients do enter a lake from the groundwater, conditions existing in the lake could reduce their impact on the water quality. For example, if groundwater recharge were beneath an existing thermocline, such as may be present during the summer growing season, added nutrients would remain trapped in the hypolimnion. The interactions between the sediments in the lake and the nutrients entering the lake via groundwater flow would tend to convert both nitrogen and phosphorus to forms unavailable for stimulation of algal growth.

Another factor contributing to the overall significance to surface water quality of aquatic plant nutrient transport from septic tank effluent is the growth limiting element in the downgradient water body. If nitrogen is the limiting nutrient in the water body of concern during the times of year of concern, as may be the case in some of the Voyager Village development area lakes, it is possible that additions of phosphorus to that water body from the groundwater would have no effect on the surface water quality.

In assessing the overall impact on surface water quality of available nutrient contributions from septic tank effluent, consideration must be given to sources and magnitudes of other nutrient inputs to the water body such as urban and agricultural runoff, point source inputs, atmospheric inputs, in addition to other sources of nutrients in groundwater such as fertilizers or sanitary landfill leachate. It is possible that the contribution of aquatic plant nutrients of septic tank effluent origin to a water body would be insignificant when compared to other nutrient sources which may be readily controllable.

From this and previous studies, it appears that, in general, phosphate will not be transported from the septic tank wastewater disposal systems to surface waters and thereby contribute to excessive fertilization problems. However, it is conceivable that there may be a very limited number of water bodies where septic tank disposal systems are located immediately adjacent to a lake and contribute sufficient phosphorus to the lake to stimulate excessive algal and/or macrophyte growth. Under these conditions, consideration should be given to either construction of a sewerage system to collect all wastewaters and provide adequate treatment for phosphate removal or modification of the septic tank wastewater disposal system to improve its phosphate retention capacity. Based on previous, unpublished work by the authors, phosphorus removal can be accomplished by the inclusion of limestone or aluminum oxide in the septic tank wastewater disposal system tile field or in a dike which is constructed below the soil surface through which the wastewaters from the septic tank tile field must pass en route to the nearby water course. Sikora et al. (1976) demonstrated the effectiveness of an individual home phosphorus removal system, using a vertical Plainfield sand column followed by a series of columns filled with calcite or dolomite. The most effective of the systems tested was one in which 0.32 cm diameter calcite particles were used. It showed 99 percent P removal during the first month but it decreased to 12

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percent in the sixth month of operation. Additional field evaluation of this approach should be made under a variety of conditions in order to determine the optimum design parameters to maximize phosphate retention. This or similar approaches using aluminum oxide is likely to be a cost-effective way to remove essentially all of the phosphorus present in septic tank wastewater disposal system effluent where there is potential for significant surface water contamination.

REFERENCES

American Public Health Association, American Water Works Association, Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 12th Edition, American Public Health Association, New York. (1965).

American Public Health Association, American Water Works Association, Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 13th Edition, American Public Health Association, New York. (1971).

American Public Health Association, American Water Works Association, Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 14th Edition, American Public Health Association, Washington, D.C. (1976).

Beek, J., F.A.M. deHaan, and W.H. van Reimsdijk, "Phosphates in Soils Treated with Sewage Water: I. General Information on Sewage Farm, Soil and Treatment Results," J. Environ. Qual. 6:4-7 (1977a).

Beek, J., F.A.M deHaan, and W.H. van Reimsdijk, "Phosphates in Soils Treated with Sewage Water: II Fractionation of Accumulated Phosphates," J. Environ. Qual, 6:7-12 (1977b).

Blackman, R.R., L.M. Slather, and C.W. Threinen,"Surface Water Resources of Burnett County," Wisconsin Conservation Department, Madison (1966).

Boyle, W.C., and L.B. Polkowski, "Groundwater Quality Adjacent to Septic Tank - Soil Absorption System," Dept. Nat. Res., Madison, Wisconsin (1970).

Brandes, M., N.A. Chowdry and W.W. Cheng, "Experimental Study on Removal of Pollutants from Domestic Sewage by Underdrained Soil Filters," National Home Sewage Disposal Symposium, Am. Soc. Agric. Engr., Chicago, Illinois (1974).

Carlson, K.G. Personal Communication to G. Fred Lee, (July 5, 1973).

Childs, K.E., "Migration of Phosphorus Wastes in Ground Waters," Geological Survey Division, Mich. Dept. of Natural Resources (May, 1974).

Corey, R.B., A.D. Hasler, G.F. Lee, F.H. Schraufnagel and T.L. Wirth, "Excessive Water Fertilization," Report to Water Subcommittee, Nat. Res. Comm. of State Agencies, Madison, Wisconsin (1967).

Cowen, W.F. and G.F. Lee, "Algal Nutrient Availability and Limitation in Lake Ontario During IFYGL, Part I, "Report to US EPA Large Lakes Research Station, Grosse Ile, Mich. (1976).

Dillon, P.J. and F.H. Rigler, "A Simple Model for Predicting the Capacity of a Lake for Development Based on Lake Trophic States," J. Fish. Res. Board, Canada 32:1519-1531 (1975).

Dudley, J.G. and D.A. Stephenson, "Nutrient Enrichment of Groundwater from Septic Tank Disposal Systems," An Inland Lake Renewal and Shoreland Management Demonstration Project Report, Upper Great Lakes Regional Comm. (1973).

Ellis, B.G., "Gull Lake Investigations: Nutrient Input Studies," Dept. Crop and Soil Sciences, Mich. State Univ. (September, 1971).

Ellis, B.G. and A.E. Erickson, "Movement and Transformation of Various Phosphorus Compounds in Soils," Soil Sci. Dept., Mich. State Univ. and Mich. Water Resources Comm. (1969a).

Ellis, B.G. and A.E. Erickson, "Gull Lake Investigation, Part II," Nutrient Input Studies, Mich. State Univ. (1969b).

Enfield, C.G., "Phosphate Transport through Soil," Prepared for presentation at the National Conference on Disposal of Residues on Land, St. Louis, Mo. (1976).

Enfield, C.G. and B.E. Bledsoe, "Kinetic Model for Orthophosphate Reactions in Mineral Soils," National Environmental Research Center, US EPA, Corvallis, Oregon, EPA-660/2-75-022 (1975).

Grim, R.E., Clay Minerology, McGraw-Hill, New York, 384 pp. (1953).

Hansen, G.L., "Groundwater Quality Adjacent to a Septic Tank-Soil Absorption System," Unpublished M.S. thesis, Univ. of Wisc., Madison, Wisconsin (1968).

Henderson, J., "Gull Lake Investigations, Part I, Demographic Survey," Mich. State Univ. (1969).

Huff, D.D. and D.A. Stephenson, "Hydrologic and Hydrogeologic Investigations of the Voyager Village Project Site, Burnett County, Wisconsin," Report to N.E. Isaacson & Associates (November, 1971).

Keeley, J., Chief, US EPA Groundwater Research Program. Personal Communication to G. Fred Lee (1976).

Lee, D.R., "The Role of Groundwater in Eutrophication of a Lake in Glacial Outwash Terrain," Int. J. Speleol., 8: 117-126 (1976a).

Lee, G.F., "Review of the Potential Water Quality Benefits from a Phosphate Built Detergent Ban in the State of Michigan," Presented at Michigan Dept. of Natural Resources Hearing on a Detergent Phosphate Ban, Lansing, Michigan (December 8, 1976b).

New York State Department of Health. The Long Island Ground Water Pollution Study, New York State Dept. of Env. Conservation (1972).

Okun, D.A. "Phosphates in Detergents - Ban or Boon?" Environmental Affairs, 2:64-79 (1972).

Reneau, R.B., Jr. and D.E. Pettry, "Phosphorus Distribution from Septic Tank Effluent in Coastal Plain Soil," J. Environ. Qual. 5:34-39 (1976).

Sikora, L.J., M.G. Bent, R.B. Corey, and D.R. Keeney, "Septic Nitrogen and Phosphorus Removal Test System," Groundwater 14:309-314 (Sept-Oct., 1976).

Smith, S.O. and D.H. Myott, "Effect of Cesspool Discharge on Groundwater Quality on Long Island, N.Y.," J. Amer. Water Works Assoc. 67:456-458 (1975).

Stephenson, D.A., "Hydrogeologic Investigations of the Voyager Village Project Site, Burnett County, Wisconsin," Report to N.E. Isaacson and Associates (February, 1971).

Stumm, W. and J.J. Morgan, Aquatic Chemistry, Wiley-Interscience, New York (1970).

Thomas, N.A. of US EPA Large Lakes Research Station, Grosse Ile, Michigan. Letter to K.A. Booman (November 30, 1976).

Tofflemire, T.J., M. Chen, F.E. Van Alstyne, L.J. Hetling and D.B. Aulenbach, "Phosphate Removal by Sands and Soils," Tech. Paper 31, New York State Dept. of Environ. Conservation (1973).

Viraghavan, T. and R.G. Warnock, "Efficiency of a Septic Tile System," J. Water Poll. Cont. Fed. 48:934-944 (1976a).

Viraghavan, T. and R.G. Warnock, "Groundwater Quality Adjacent to a Septic Tank System," J. Amer. Water Works Assoc. 68:611-614 (1976b).

Wirth, H.E. and R.C. Hill, Summary Report of a Survey of Private Sewage Disposal Systems Serving Water Front Properties, Wisconsin Department of Health and Social Services Division of Health, Madison, Wisconsin (1967).